EXPERIMENT MANAGEMENT SYSTEM, METHOD AND MEDIUM

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BACKGROUND OF THE INVENTION

Field of the Invention

The present invention concerns computer-related methods systems and mediums for managing experiments. More specifically, it relates to managing experiments concerning changes in a process, for example processes for controlling semiconductor technology manufacture.

Related Art

Machines, materials and processes in most industries are becoming increasingly complex and costly. Meanwhile, a need has arisen for the continuing improvement of processes and of machine and material quality.

Semiconductors and other products are typically manufactured under control of pre-defined processes. These pre-defined processes may be highly complex. For example, a pre-defined manufacturing process for producing semiconductor chips might contain five hundred to seven hundred and fifty steps. Moreover, each of these steps might have several variables, for example six variables, that are significant.

In order to improve manufacturing or test theories, it is often desirable to perform experiments by changing some small portion of the base manufacturing process. For example, an engineer might want to make one of the layers on a semiconductor ten percent thicker. This might entail performing the recipe for that step for an extra 15 seconds, with perhaps some adjustments in subsequent steps. Typically the engineer does not create a new base process including the modifications to adapt to the desired test, since that would be too time consuming.

Unfortunately, such an experiment using conventional techniques requires manual intervention and manual tracking of results. Accordingly, the engineer or operator performing the experiment would obtain a number of semiconductor chips and process them outside of an automated (e.g., production or mock-production manufacturing) environment. Thus, the products on which the experiment is performed need to be removed from the automated environment, which is both time-consuming and allows for the potential introduction of extraneous factors which may ultimately (and inadvertently) affect the results of the experiment. In addition, such removal of the semiconductor chips makes it difficult to coordinate manual tracking of changes or experiment history, and to control experiments and to analyze overall results.

Consequently, for research and development engineers, operators and other users working in factory settings, there remains a need for experiments on changes to existing processes to be flexible, easy and traceable.

SUMMARY OF THE INVENTION

The present invention alleviates the problems of the conventional techniques described above by providing systems, methods and mediums for automating experiments within an automated (e.g., production or mock-production manufacturing) environment without the need to disassociate the test subject (e.g., the semiconductor chip or chips) from that environment. An "experiment," according to at least some embodiments of the present invention, is a pre-planned deviation of at least some portion of an established (e.g., pre-defined) process utilizing the automated environment.

According to at least some embodiments of the present invention, experimentation begins with an experiment order (i.e., request to initiate an experiment), which is first originated as an informal request, submitted to a computerized system, routed through various defined users, perhaps modified, and ultimately approved. In facilitating the implementation of the requested

experiment, experiment management includes four conceptually distinct stages: order management, setup, execution, and analysis. The order management component of the invention assists in automatically navigating the formalization of the experiment order (mentioned above) and tracking the experiment. The setup stage typically handles the manual or automated translation of the experiment from the generalized statements, requirements, or proposed results into data defining a specific process ready to execute by the automated environment. The execution stage includes the execution of the experiment itself via the automated environment based on the process data, including the collection of experiment results. In the analysis stage, results of the experiment are reported and analyzed.

In accordance with at least some embodiments of the present invention, in operation, an experiment order is received, the experiment order including at least some deviation from a base process capable of operating in an automated environment. An approval of the experiment order is then obtained. At least a portion of the experiment order is translated into processing data suitable for implementation by said automated environment, and stored. The experiment is caused to be executed in conjunction with at least some portion of said base process via the automated environment according to the processing data.

Further, the invention may include storing data defining the experiment order, distributing the experiment order to a plurality of users, obtaining changes to the experiment order from at least one of the users, and receiving the approval for the experiment order from at least one user. Moreover, documents may be attached to the experiment request.

Additionally, information indicating a state change of the experiment request may be published, responsive to a document attached to the experiment request or to a change in state of the experiment order.

Moreover, the experiment may produce at least one test product and at least one production product (i.e., a control, which could be, e.g., a product which was processed before or after the test product, and which was processed according to the base process); the processing

data may include an indication of the base process, the changes to the base process, and a split-off of a control set (i.e., the products subject to the experiment); and the split-off of a control set may produce the at least one production product according to the base process and the changes to the base process may produce the at least one test product. The results of the execution of the experiment may be stored.

BRIEF DESCRIPTION OF THE FIGURES

The above mentioned and other advantages and features of the present invention will become more readily apparent from the following detailed description in the accompanying drawings, in which:

Figure 1 is a block diagram of a computerized process control system which may be used in connection with at least some embodiments of the present invention.

Figure 2 is a flow chart of an overall process for experiment management according to at least some embodiments of the invention.

Figures 3A and B are a flow chart of an order management process portion of the overall process of Figure 2.

Figure 4 is a flow chart of a setup process portion of the overall process of Figure 2.

Figure 5 is a flow chart of an execution process portion of the overall process of Figure 2.

Figure 6 is a flow chart of an analysis process portion of the overall process of Figure 2.

Figure 7 is a diagram illustrating definition of an experiment.

Figure 8 is an exemplary user interface for an experiment editor, used in connection with at least some embodiments of the present invention.

Figure 9 is an exemplary user interface for the experiment editor, illustrating attachments, used in connection with the invention.

Figure 10 is an exemplary user interface for an experiment editor, illustrating experiment content, used in connection with at least some embodiments of the present invention.

Figure 11 is an exemplary user interface for an experiment editor, illustrating wafer level split details, used in connection with at least some embodiments of the present invention.

Figure 12 is an illustration of at least some embodiments of an experiment.

DETAILED DESCRIPTION

The following detailed description includes many specific details. The inclusion of such details is for the purpose of illustration only and should not be understood to limit the invention. Throughout this discussion, similar elements are referred to by similar numbers in the various figures for ease of reference.

As indicated above in the Summary section, an "experiment," according to at least some embodiments of the present invention, is a pre-planned deviation of at least some portion of a base process utilizing an automated environment. Typically an experiment is performed on materials, such as semiconductor chips, that are produced as a result of the automated process. Also as indicated above, at least some embodiments of the present invention envision that experiment management includes four conceptually distinct stages: order management, setup, execution, and analysis. Although these stages are conceptually distinct, they may temporally overlap.

According to at least some embodiments of the present invention, reports, memos, forms, files, and other documents may be associated with a particular experiment throughout the order management and setup stages. These may be reviewed by users allowed access to the experiment. This permits users and reviewers to comment on the experiment, provide background information, provide appropriate forms, attach relevant information, etc., in a user-friendly, highly flexible fashion. Due to its flexibility, it invites users to provide input and should result in higher quality experiments.

Reference is now made to Figure 1, a block diagram generally illustrating a computerized process control system which may be used in connection with at least some embodiments of the

present invention. As is illustrated, the experiment order 101 is input to a computerized system, referred to generally as a controller 103. The experiment order 101 contains a description, such as in text, of a desired experiment. The experiment order 101 could be, for example, a word processing document containing text. As one alternative, it could be input from a menu. The experiment described in the experiment order 101 is a deviation from an existing automated process for creating a product, although it is not necessarily described in the order as a deviation from a particular process.

The controller 103 has access to various stored processes 111, such as manufacturing processes for semiconductor chips. The controller 103 could be a general purpose computer, or a special purpose computer specially programmed, or other automated system or distributed system. (In general, such computers as used here, or whose use may be apparent from the context of the discussion, can be any number of different types of computers, including those containing processors from Intel Corporation of Santa Clara, CA, wherein these computers can contain any number and different types of storage devices serving as computer-readable mediums; in addition, it is contemplated by at least some embodiments of the present invention that the computer-readable medium be a transmission). The stored processes 111 comprise a number of automated steps in a manufacturing process. The actual format of the contents of these steps is defined by the system and devices in the system. Some of the steps in the processes utilize recipes, stored in a recipe database 113. Recipes may be shared by various processes. The controller 103 controls the processing of an automated environment such as production system 105, which ultimately produces production products 107, or following an experiment, produces test products 109. The invention thereby allows users to submit experiment requests, create derivations of base processes, and to track the status of experiment requests.

Reference is made to Figure 2, a flow chart of an overall process for experiment management according to at least some embodiments of the present invention. The four

conceptual stages (as mentioned above) included: order management 201, Manufacturing Execution System (MES) setup 203, execution 205, and analysis 207.

At the order management stage 201, further defined below, the experiment order is defined. Typically, an experiment would be defined in the experiment order as a set of requirements, and may be specified as a deviation from an existing process. The experiment order is subject to routing, review, and change by various personnel, prior to being approved for the next stage.

At the MES setup stage 203, the experiment order is translated into the experiment setup, that is, specific processing data which can be executed by components in the production system. The processing data is in a format which is expected by the production system components. In typical situations, data to execute the experiment is interjected between (and/or replaces existing) steps of a base process.

At the execution stage 205, the execution of materials is performed, based on the experiment setup. Most or all of this stage is performed automatically by the production system components. The results of each step in the setup implemented at this execution stage 203 are recorded.

At the analysis stage 207, the results of the experiment are reported and analyzed. This may be done automatically by a computer, and/or may include analysis by the user.

Reference is made to Figures 3A and 3B, a flow chart of an example order management stage 201 of the overall process of Figure 2, as envisioned by at least some embodiments of the present invention. This stage allows the experiment to be requested and be performed following experiment request review and sign-off. At step 301, the experiment is initially defined by a requestor. In order to facilitate experiments, it is envisioned that requests can be submitted in any appropriate form. One appropriate form is a textual description in an electronic document. Note that the experiment may be informally described. It is not necessary for the initial experiment request to define the experiment as a variation from an existing process.

At step 303, the experiment object (or other storage for experiment data) is created. Initial information is collected to identify the requestor and the experiment. The information is stored, such as in an object. The experiment request is then distributed to appropriate users identified in a distribution list.

At step 305, a user who received the experiment request (e.g., for review) may attach external files, memos, forms, or other documents to the experiment request. The ability to associate documents with the experiment request can be used to facilitate user interaction concerning the experiment request. These documents may then be reviewed by other users.

At step 307, the user (or automated entity) determines the changes to be made to a particular base process. The user (or automated entity) may also determine the base process which is to be modified. Also, at step 309, the user (or automated entity) will determine when to split off a lot from the control set, and the lot-specific transactions that are to be made. At step 311, the user (or automated entity) determines what recipe changes, if any, need to be made. Having determined the specified changes to be made to the base process, the system receives and stores the changes as processing data. At step 313, the experiment, as it has been tweaked by the users, is sent for sign-off, described in Figure 3B. At step 315, if the experiment has been approved by the users, the process ends 317 and the experiment proceeds to the next conceptual stage. Otherwise, the process returns to step 305 for further handling.

Figure 3B illustrates one embodiment of the sign-off process. At step 321, a user who received the experiment request (e.g., for review) may attach external files, memos, forms, or other documents to the experiment request, which may then be reviewed by other users. At step 323, if documents are attached or deleted to the experiment request, or at step 325 if there was a state change for the experiment request, such information is published 327. One appropriate method for publication is to send such information to listed users via e-mail. A state change would include, for example, a "sign-off" on the experiment (or portion thereof). At step 329, if

an indication of final approval (or affirmative lack of approval) has not been received, the process repeats at step 321. If final approval has been received, the stage is ended 331.

Reference is made to Figure 4, a flow chart of a setup stage 203 portion of the overall process of Figure 2. During the setup stage, a user can set up the particular experiment. For example, a user could set up experiment-specific data, for example a reticle or recipe details. At step 401, a user (or automated entity) retrieves and reviews the experiment order. As indicated above, the experiment order may be an informal description of an experiment. A user can determine how a process should be implemented to effect the requested experiment, or the process can be automated, for example, by parsing the description of the experiment and identifying certain key words or phrases that are indicative of what is requested. At least some embodiments of the present invention envision that this can be done utilizing, e.g., various expert system techniques. At least some embodiments of the present invention also envision some combination of automation and user participation.

Still referring to Figure 4, at step 403, the user (or automated entity) determines the changes to be made to a particular base process. The user (or automated entity) may also determine the base process which is to be modified. Also, at step 405, the user (or automated entity) will determine when to split off a lot from the control set, and the lot-specific transactions that are to be made. At step 407, the user (or automated entity) determines what recipe changes, if any, need to be made. Having determined the specified changes to be made to the base process, the system receives and stores the changes as processing data.

Reference is made to Figure 5, a flow chart of an execution stage 205 of the overall process of Figure 2. At this point, the experiment has been defined in processing data which can be input to the automated environment. The experiment can then be processed in a manner which is transparent to the automated environment. At step 501, the automated environment receives the processing data for the modified process. At step 503, the automated environment executes a step of the processing data. If there are any test results to be stored, at steps 505-507,

the system stores the test results. At step 509, if processing is not complete, the automated environment returns to continue processing at step 503. When processing is complete, this stage ends at step 511.

Reference is made to Figure 6, a flow chart of an analysis stage 207 of the overall process of Figure 2. Experiment history setup information and history data is available for use in analysis and reporting. The experiment results are collected at step 601. At step 603, the experiment results are made available for any analysis. For example, a user may wish to make a manual analysis of the results. At step 605, the automated environment performs any requested computerized analysis. If there are any proposed changes to the experiment, at steps 607-609, the user may generate another experiment request. The analysis is completed at step 611.

Reference is made to Figure 7, a diagram illustrating the defining of an experiment, as contemplated by at least some embodiments of the present invention. Specifically, the experiment 701 initially is associated with stored data including attribute information 703, for example defined by the user, and operation information 705, defining how the experiment operates. An experiment initially may be created from scratch, or may be copied from another experiment used as a template. Typical attributes would include sufficient information to identify useful information about the experiment, such as an experiment identifier, an experiment objective, a requestor name, an experiment name, a requestor e-mail address.

When the experiment is initially defined, a starting state will be "underchange" 707 (indicating that the experiment may be changed), and once the experiment is approved, the ending stage is effective (distributed) 711. There may be a series of user-defined states 709 which are under control of the user, subsequent to the underchange state, and prior to the effective state. The effective state is entered after the experiment is approved and signoff is obtained. Preferably, a user cannot change the contents of an experiment without appropriate permission. There may be other user-defined attributes, as well as attached external documents and/or files, and a user-defined state model. According to one possible implementation, the

experiment is implemented as an object. Note that this state table corresponds to the order management process portion.

Figures 8-11 are examples of a potential user interface to be used in connection with at least some embodiments of the present invention. First, reference is made to Figure 8, one aspect of an exemplary user interface for an experiment editor. Here, the user may provide information about the experiment 811, about experiment attributes 813, and optionally about experiment category 815. Experiment information may include an objective 801, which may summarize a description of the experiment. Other experiment information includes requestor identification information 803 (for example, name, e-mail address); the basic process or state model 805 for the experiment; and optionally an effective date 807 after which the experiment request will expire. The information collected in this initial interface is associated with the experiment request.

Reference is made to Figure 9, another aspect of an exemplary user interface for the experiment editor, illustrating attachments used in connection with at least some embodiments of the present invention. In such embodiments, documents such as files, memos, forms, web addresses, etc., without limitation, may be attached to or otherwise associated with the experiment request. Figure 9 lists, by way of example, several documents, by file name 909, which are attached to the experiment request: a local document experiment.doc 901; a filepath for another document C:\Experiment\Experiment.doc 903; a web site www.consolium.com 905; and an http document http://www.consilium.com/corp_events.html?phase=ge 907. The user interface of the present example also indicates whether or not the file is simply a reference 911.

Reference is made to Figure 10, another aspect of an exemplary user interface for the experiment editor, illustrating experiment content, used in connection with at least some embodiments of the present invention. This exemplary user interface allows access to experiment content 1001, physical split details 1003, and merge details 1005, the split treating the standard and test materials differently, and the merge detailing how the standard and test

materials are treated when merged after the split. The experiment content 1001 provides the file controlling the experiment process. Here, it names the experiment process 1007, the experiment route 1009, and the experiment operation 1011. Note that additional information on the experiment may be provided, such as whether the processing is pre- or post-split 1013.

Reference is made to Figure 11, an exemplary user interface for the experiment editor, illustrating wafer level split details, used in connection with the invention. Here, the processing data provides specifics, at lot level, slot level, or unit level 1101. The present example concerns a slot level split. As is illustrated, the split details 1103 provide the slots and the quantity to be split; as well as the process plans 1105 to be associated with each split.

Reference is made to Figure 12, illustrating at least some embodiments of an experiment as contemplated by the present invention. Each experiment order 1201 may have associated with it various documents, such as files 1203, forms 1205, memos 1207, and experiment results 1209. Users can add or delete the document to/from the experiment order. Preferably, an attachment of a document will be considered an event, and may result in the publication of the event for example by e-mail or Workflows.

An experiment order may be copied by a user, together with attached documents, attributes, and other correlated information

Also, according to at least some embodiments of the present invention, changes to the experiment order are stored in a history. Stored changes could include changes to native attributes, external document additions/deletions, and associated with other objects.

Consider an example of an experiment, with reference to Figures 3 through 6. In this example, the user wants a specified layer of a chip to be 10 % thicker. The experiment in this example is an idea from an engineer. The experiment request is defined by a user, and submitted to the system at step 301 through 303. It could be a very general request with a simple textual description. An experiment object is created for the experiment request, and the experiment request is routed to the appropriate users for approval, at steps 305 through 313. The approval

may be automated, such as delivery via e-mail awaiting a marking as approved. As shown in steps 321 through 329, until sign-off is received for the experiment, users may attach and/or delete relevant files, memos, etc. to the experiment object. If there are attachments or deletions, or if the experiment has changed state, the event is published to the users, shown in steps 323 through 327. The review process continues until sign-off is received.

Once sign-off is received, the experiment order is reviewed and translated to processing data, as shown in Figure 4. This review and translation may be a manual process done by a person with the appropriate experience. In addition, it may also be performed (in whole or part) by automated means. In any event, it could be determined at step 403, for example, that wafers 1 – 11 in the lot will be the control (i.e., the established steps will not be effected), and the remainder of the wafers in the lot will be the test product. Also, it could be determined that a particular parameter in the 500th cycle of a standard base process must be changed from 100 to 200. It would be specified at step 405 that the controls will be split off from the other processing. If it was necessary, a new recipe would be created or an existing recipe would be modified at step 407. All of the wafers will be under automated control. The two lots will be re-united and held or delivered for analysis. The information related to the variations from the base process, specific execution transactions, and any recipe change are stored as processing data. Note that the experiment could call for additional or different information to be collected as part of the processing results.

The experiment is then run, as shown in Figure 5. At this point, the experiment processing data are handled no differently from a regular control job. That is, no exception processing is required. The processing data is input into the manufacturing system at step 501, and the test proceeds automatically by executing the processing data at step 503. Test results that are generated during execution of the experiment are stored at steps 505-507.

Following the experiment, test product might be reclassified from test materials to standard production materials, if within tolerances, and shipped to customers. Alternatively, the

non-standard processed materials could be scrapped, or saved for further analysis, as shown in Figure 6.

While this invention has been described in conjunction with the specific embodiments outlined above, many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, the preferred embodiments of the invention as set forth are intended to be illustrative and not limiting. Various changes may be made without departing from the spirit and scope of the invention as defined in the following claims.

For example, it would be possible to define an entire experiment from scratch. A typical semiconductor manufacturing process is 500 to 750 steps, so it may often be more efficient to define an experiment as a variation from an existing process.

As another example, the controller may be a general purpose computer, a specially programmed special purpose computer; it may also be implemented as a distributed computer system rather than as a single computer.